Modern Electronic Metrology

OPERATING INSTRUCTIONS

MODEL 9120

POTENTIOMETER

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GUILDLINE INSTRUMENTS

OPERATING INSTRUCTIONS

MODEL 9120

POTENTIOMETER

GUILDLINE INSTRUMENTS LIMITED

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POTENTIOMETER TYPE 9120

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POTENTIOMETER TYPE 9120

1. GENERAL

The Type 9120 is a "double" or tandem potentiometer giving seven figure resolution on four dials. Dials I and II are part of potentiometer 1 and dials III and IV are in the circuit of potentiometer 2. The two potentiometer circuits are supplied from separate power sources. Potentiometer 1 is standardized against an external standard cell and potentiometer 2 is standardized against potentiometer 1. Pot. 1 is supplied from a 6 volt lead-acid battery and pot. 2 may be supplied from either a 2 volt lead-acid battery with series resistance or a Zener diode battery substitute giving approximately 1 volt and operating from line voltage.

2. CONSTRUCTION

The switches and all electrical components of the potentiometer are mounted on a panel of specially selected high insulation material. The outer wooden case is of ruggedized Formica construction and is lined with thermal insulation and an aluminum electrostatic shield which is connected to the top panel and ground terminal.

3. DIALS AND TERMINALS

3.1) Measuring Dials

The potentiometer has four measuring dials giving voltage increments as follows. There is no range change and all four dials have potential contacts only.

Dial I	20 steps of 0.1 volt	2.000 000 0
Dial II	99 steps of 0.001 volt	0.099 000 0
Dial III	99 steps of 0.000 01 volt	0.000 990 0
Dial IV	99 steps of 0.000 000 1 volt	0.000 009 9
	Total	2.099 999 9

In addition, the 100th position of dials II, III and IV are marked CK, for use in the self check procedure and make the maximum setting of the four dials sum to 2.101 010 0 volts. Dials II, III and IV have an extra heavy detent between

the CK and 0 positions to indicate to the operator that a full dial increment is taking place as the dial is rotated through one step.

3.2) Standardize Switch

The Standardize Switch has a center "OFF" position and may be rotated through low, medium and high sensitivity positions to connect the standardizing galvanometer to the standard cell circuit of Pot. 1 and in the opposite direction through low, medium and high sensitivity positions to connect the standardizing galvanometer for comparison of the total of dial III and one step of dial II, when standardizing Pot. 2 against Pot. 1.

3.3) Current Controls

The current in Pot. 1 (20mA) is controlled by three decade dials marked x10, x1 and x0.1 and by two continuously variable dials marked Fine 1 and Fine 2. The current in Pot. 2 (40uA) is controlled by a continuously variable 5000 ohm resistor located adjacent to the BA2 terminals and marked C2.

3.4) Standard Cell Dial

The standard cell voltage range is from 1.017 500 volt to 1.020 100 volt. This voltage range is covered in 25 steps of 100uV plus 100uV on the concentric continuously variable dial. The smallest marked dividion is 2uV and resolution is better than 1uV.

3.5) Galvanometer Sensitivity Keys

The five galvanometer sensitivity keys are marked 1, 2, 3, 4 and R and provide four sensitivity conditions and a reversal. In the No. 1 sensitivity an effective resistance of 20 Megohms is connected in series with the galvanometer, in the No. 2 sensitivity position a resistance of 500,000 ohms, and in the No. 3 position a resistance of 10,000 ohms. The externally connected galvanometer damping resistor shunts the galvanometer terminals at all times except when the No. 4 and R keys are depressed. In the high sensitivity condition the damping resistor is removed

from the circuit. Depression of any one of the five press keys automatically releases any previously depressed key. The No. 1 key may be rotated from the "tapping" (white dots horizontal) position to the "lock-down" (white dots vertical) position, as required.

3.6) Meas. Stand Keys

The four press buttons on the right of the panel, engraved MEAS STAND, IN OUT are used as follows. For measurements on the four potentiometer dials press the MEAS button in the "lock-down" condition. To standardize, lock down the STAND button, which releases the MEAS button. The T2/T3 IN and OUT buttons are used in the self-check procedure as described in Para. 7.

3.7) EMF $\pm$ Keys

Two press buttons in the centre of the panel enable reversal of the emf polarity without reconnecting the leads.

3.8) Terminals

The nine pairs of terminals are designated as follows:-

BA1	For connection of a 6 volt lead-acid battery supplying Pot. 1. Polarity marked.
SC	For connection of a standard cell. Polarity marked.
SC GA	For connection of a separate standardizing galvanometer if required. (Type 9450, 50 ohm). (The Test Galvanometer may be used in both standardizing and measuring operations if a second galvanometer is not available.)
TEST GA	For connection of the measuring galvanometer. Recommended: Type 9460 Photocell Galvanometer Amplifier and 9461A Secondary Galvanometer.
GD	For connection of a galvanometer damping resistor across the terminals of the test galvanometer. This resistor is disconnected when the H^+ and H^- galvanometer sensitivity keys are pressed. A damping resistor is not required when using the 9460/9461A combination.
EMF	For connection of the voltage to be measured. Polarity marked. For extension to four or five measuring circuits the Type 9145A Push Button Selector Switch should be connected as an external accessory.

CK3	As shown in the circuit diagram if these terminals are short circuited the resistance of the battery circuit of Pot. 2 is reduced by 25,000 ohms. The current is thus increased to approximately 40mA and the range of dials III and IV is increased to 1 volt. This increases sensitivity when checking linearity of Dial III as described in Para. 7.5.
T2, T3	Used in the self check procedure described in Para. 7.
BA2	For connection of a Zener diode d.c. source supplying 40uA at 1 volt or alternatively a 2 volt lead-acid battery with a series resistance (carbon) of approximately 25,000 ohms. Polarity of these terminals is marked.

4. ELECTRICAL CIRCUIT

4.1) The elements of the electrical circuit of the potentiometer are shown in the enclosed circuit diagram.

4.2) Test Galvanometer Circuit

With the MEAS button locked down, the Test Galvanometer is connected in series with the galvanometer sensitivity keys, the four measuring dials and the EMF terminals. When the four measuring dials are in the zero position the potentiometer presents a resistance of approximately 1 ohm. This resistance increases to approximately 130 ohms with the four dials set to maximum reading.

4.3) Switches

All the switches in the potentiometer are of copper construction. In some cases the emphasis is on good reproducibility of contact resistance and in others the emphasis is on the reduction of thermal emfs to a minimum. In the current control rheostat it is important that contact resistance shall be small and stable. In the measuring dials it is important to minimize thermal emfs and the design is such that temperature gradients which give rise to such thermal emfs are minimized. Since none of the measuring dial contacts carry current small variations of contact resistance are unimportant.

4.4) Electrostatic Shield

The aluminum top panel and the box lining are connected to the "GND" terminal. These constitute an effective electrostatic shield on the potentiometer circuit components.

5. BATTERY SUPPLIES

A six volt battery is required to supply Potentiometer 1. This should be connected to the battery terminals and should remain connected except when removed for recharging. A battery of the charge-retaining type with a capacity of 100 AH is recommended (Willard Type DD-3-3). This type of battery can be expected to last for approximately 12 months on one charging and if not disconnected will remain very stable.

When a newly charged battery is connected to the potentiometer, the current value can be expected to drift for several hours and frequent checks on standardization will be necessary.

NOTE: If the circuits to be measured are grounded or have a leakage resistance to ground it is important that the battery be adequately insulated. It is good practice to standathe battery on blocks of wax or other clean high insulatiom resistance material.

Potentiometer 2 requires 40 microamps at 1 volt at the BA2 terminals. This may be supplied from a Zener diode source operatingffrom the 110volt line or alternatevely from a 2V lead-acid battery with 25,000 ohms in series. This series resistance may be a carbon resistor.

6. OPERATION AS A POTENTIOMETER

6.1) Installation

6.1.1) The potentiometer may be installed on a level bench or with the front panel vertical as required. The location of the potentiometer should be carefully chosen to avoid proximity to heating equipment or electrical equipment with a large heat dissipation. Outside windowas from which cold air currents may be exprected, or through which sunlight could

fall on one side of the potentiometer should also be avoided.

6.1.2) Mount the galvanometer amplifier Type 9460 on a stable base, preferably not the working bench, but in a position where the front controls are easily accessible. A small rigid stand on the floor below the bench is recommended. Mount the secondary galvanometer associated with the amplifier behind the potentiometer and with the scale slightly below eye level.

6.2) Connections

6.2.1) Connect the battery supplies to the BA1 and BA2 terminals. (See Para. 5)

6.2.2) Connect the measuring galvanometer to terminals marked TEST GA and the critical damping resistor for the galvanometer to the terminals marked GD. (Not required if 9460/9461A is used)

6.2.3) Connect the standardizing galvanometer to the SC GA terminals. (Recommended Type 9450, 50 ohms) Note that if a separate galvanometer is not available for the standardizing circuit the measuring galvanometer may be used. If a damping resistor is not used across the GD terminals the measuring galvanometer may be connected simultaneously to both the TEST GA and SC GA terminals, and may be used in either circuit by operating the appropriate switches as described below.

6.3) Standardization

6.3.1) Press the lock down the STAND button and turn the STANDARDIZE switch to OFF.

6.3.2) Connect the standard cell leads to the SC terminals on the potentiometer. Connect the other end of these leads to the standard cell in correct polarity.

6.3.3) Set the SC dial to the known voltage of the standard cell.

6.3.4) Turn the STANDARDIZE switch in a CW direction to 1L (low sensitivity). This connects the standard cell in series with the standardizing galvanometer to 9 steps of dial 1 plus the total of dial 2 and the standard cell dial through a 10 megohm resistor. Note the galvanometer deflection and adjust the current control rheostat commencing with the x10 dial and proceding through x1 and x0.1 to the Fine controls. Increase galvanometer sensitivity by rotating the STANDARDIZE switch to 1M (medium sensitivity; 100,000 ohms) and finally to 1H (high sensitivity; zero resistance) to produce zero galvanometer deflection at full sensitivity. Potentiometer 1 is then standardized against the standard cell.

6.3.5) Rotate the STANDARDIZE switch through OFF to 2L. This switch position connects the first step of dial II (1mV) in series with the standardizing galvanometer and in opposition to the voltage across the total of dial III. Adjust the current in Potentiometer 2 by the screwdriver operated trimpot accessible through the hole in the terminal strip adjacent to the BA2 terminals. Increase sensitivity through 2M to 2H for final adjustment. Potentiometer 2 is then standardized against Potentiometer 1.

6.4) Voltage measurements below 2 volts

6.4.1) If there is some doubt about the magnitude of the voltage to be measured, make a preliminary check with a multimeter.

6.4.2) Connect the circuit to be measured to the emf terminals in correct polarity.

6.4.3) Adjust the mechanical zero of the measuring galvanometer to

zero, press the low sensitivity galvanometer key (L) and adjust the four measuring dials for zero deflection on the galvanometer.

6.4.5) Progressively increase galvanometer sensitivity to medium and high by depressing the M and H+ keys and rebalance on the four measuring dials.

6.4.6) Reverse the measuring galvanometer by pressing the H- key and re-adjust the measuring dials until the deflection (not necessarily zero) does not change on reversal. This eliminates from the reading the effect of thermal emfs in the galvanometer and galvanometer leads.

Check standardization of Potentiometer 1 by rotating the STANDARDIZE dial to 1H. Make adjustments to the Potentiometer 1 current as necessary. Restore the STANDARDIZE dial to OFF and rebalance. The reading of the measuring dials then indicates the measured voltage. Note that if a separate standardizing galvanometer is used the standardization of Potentiometer 1 can be observed at the same time as the final balance is made on the measuring dial.

It is not normally necessary at this stage to check the current in Potentiometer 2, since a change as large as 0.01% in Potentiometer 2 current would cause a change of only 0.1μF if the total of dials III and IV were in use.

6.5) Voltage Measurement Above 2 volts

6.5.1) Connect the voltage E to be measured to the input terminals of a volt ratio box and the output terminals of the volt ratio box to the emf terminals on the potentiometer in the correct polarity.

6.5.2) The input terminals used on the volt ratio box should be such as to give an output voltage 'e' which will utilize all four measuring dials

on the potentiometer.

6.5.3) Measure the volt ratio box output voltage 'e' as described above. The total voltage E is given by:

$$E = dR$$

where d is the reading of the four measuring dials,

R is the ratio of the volt box for the particular terminals used.

6.6) Current Measurement

6.6.1) Connect the current circuit to be measured to the current terminals of a 4 terminal standard resistor having a resistance value such that the voltage appearing at the potential terminals gives maximum discrimination on the measuring dials of the potentiometer.

6.6.2) Connect the potential terminals of the four terminal standard resistor to the emf terminals on the potentiometer in correct polarity.

6.6.3) With the potentiometer correctly standardized, obtain a balance on the measuring galvanometer as described above.

6.6.4) The magnitude of the current in the standard resistor is given by $I = \frac{E}{R}$ where E is the potentiometer reading and R is the resistance of the four terminal standard.

6.7) Resistance Comparison

NOTE: IT IS NOT NECESSARY TO STANDARDIZE THE POTENTIOMETER AGAINST A STANDARD CELL FOR RESISTANCE COMPARISONS, BUT POTENTIOMETER 2 CURRENT SHOULD BE ADJUSTED TO STANDARDIZE POTENTIOMETER 2 AGAINST POTENTIOMETER 1. (see Para. 6.3.5)

6.7.1) Connect the two 4 terminal resistors to be compared in series through their current terminals and in series with a suitable current control resistor and battery supply and adjust the current to produce an emf that may be measured on the potentiometer.

6.7.2) Connect the potential terminals of the standard resistor and the resistor to be measured to the EMF terminals of the potentiometer through double pole sections of a Type 9145A or equivalent selector switch so that each may be connected to the potentiometer in turn.

6.7.3) Set the potentiometer dials to 1.000 000 0 and with the standard resistor connected to the EMF terminals adjust the current through the resistors until a zero deflection is obtained on the galvanometer with the high sensitivity key pressed.

6.7.4) Switch the 9145A selector switch to connect the measured resistor to the potentiometer and without re-adjusting the current in the potentiometer or resistors obtain a balance at maximum galvanometer sensitivity by adjustment of the four measuring dials. The ratio of the standard to the measured resistor is given by the ratio of the two settings of the measuring dials, the first of which was 1.000 000 0.

6.8) Comparison of standard cells

6.8.1) Connect the known standard cell to the SC terminals and up to four standard cells to be measured to the four circuits of a Type 9145A selector switch taking particular care to connect the same polarity in each case and making connections to the cells last in order to avoid accidental short circuits. Connect the potentiometer side of the four selector circuits to the EMF terminals on the potentiometer.

6.8.2) Set the standard cell dial to the known voltage of the standard cell and standardize Potentiometer 1 and Potentiometer 2 as described in Para. 6.3.

6.8.3) Press the MEAS button with the measuring dials initially set to 1.018 000 0 volt and balance the potentiometer against each cell to be

measured using the four measuring dials. Read the voltage of each cell as indicated by the dial setting at balance.

NOTE: Since the same resistors are used for the standard cell circuit and for dials I and II it is not possible to have any significant error between the two circuits.

6.8.4) ALTERNATIVELY, standard cells may be compared by connecting them in series opposition and measuring the difference on the potentiometer. In this method it is not necessary to have the potentiometer very accurately standardized since it is probable that the measured difference will not exceed 1000uV and in such case standardization of the potentiometer to 0.1% will give standard cell voltages which are accurate to 1 part in 10^6. It is, however, important to be very careful in determining polarities of the cells and of the difference added by the potentiometer so that it is known which cell has the higher voltage.

7. SELF-CHECKING PROCEDURE

The linearity of the potentiometer can be checked by use of the built-in checking resistors.

7.1) Equipment Required

7.1.1) A second potentiometer with similar discrimination to the Type 9120 but not necessarily linearly accurate. (Note that the second potentiometer is not used as a standard. It is used only as a convenient and adjustable source of emf.)

7.1.2) A galvanometer of other detector giving a sensitivity of 100mm/uV in a total circuit resistance of 200 ohms. (Recommended Type 9460 and 9461A).

7.2) Linearity Check on Dial I

7.2.1) Dial I should be checked step by step against the total of Dial II

by the following procedure.

7.2.2) Connect the external potentiometer to the EMF terminals. Short circuit the emf terminals on the external potentiometer and connect the galvanometer to the TEST GA terminals. Press the MEAS button, turn dial I to 0.1 volt and dials II, III and IV to zero. Adjust the external potentiometer to approximately 0.1 volt, and with increasing sensitivity adjust the current in either the external potentiometer or in Potentiometer 1 for zero deflection on the galvanometer.

7.2.3) Release the galvanometer key, restore Dial I to zero and turn Dial II to CK. Press the high sensitivity key and record the galvanometer deflection due to the difference between the first step of Dial I and the total of Dial II.

7.2.4) Balance two steps of Dial I against the external potentiometer with Dial II at zero. Reduce the setting of Dial I to 1 and increase Dial II to CK. Observe the deflection due to the difference between the second step of Dial I and the total of Dial II.

7.2.5) Repeat the same procedure for each step of Dial I up to 20. Check the sensitivity of the galvanometer before each comparison. It is easily possible to obtain a comparison between steps to $\pm$0.1 microvolt equivalent to $\pm$1ppm throughout the dial, provided that the current in both potentiometers is stable. In the upper half of the dial however, it will be found that care is necessary to avoid errors due to differing rates of current drift in the two potentiometers.

7.2.6) If Δ G is the difference between one coil of dial I and the total of dial II, the average difference between each of the coils of dial I

and the total of dial II is given by:-

$$\overline{\Delta G} = \frac{1}{10} \sum_{x=1}^{10} \Delta Gx$$

The difference between each individual difference and the average difference is

$$\Delta Gx - \overline{\Delta G} = \Delta Gx - \frac{\sum_{x=1}^{10} \Delta Gx}{10}$$

and the deviation Dn from perfect linearity at the nth step is given by the algebraic sum of the deviations from the average between zero and the nth step:

$$Dn = \sum_{x=1}^{n} \left[\Delta Gx - \frac{\sum_{x=1}^{10} \Delta Gx}{10} \right]$$

An example of the linearity computation for the first 10 coils of dial I is given in Appendix I. If the arithmetic is correct the last figures in columns 4 and 5 should always be zero. The figures in column 5 can be plotted to show the linearity of dial 1 over the first 10 steps and the operation can be extended to step 20, although it is normal to allow $\overline{\Delta G}$ to cover only the first 10 steps of dial 1 so that the error will always be zero at the 1 volt point. This is justifiable on the grounds that it is at the 1 volt point at which the potentiometer is standardized and therefore, within the accuracy of the standard cell, must be considered without linearity error.

In the example given, the galvanometer deflections for steps 11 to 20 may be compared with $\overline{\Delta G}$ in column 3, summed in column 4 and converted to micro-volts in column 5 and the plot of linearity can be continued from zero error

at step 10 to cover the upper half of the dial.

Corrections for any step of dial I can be read directly from this graph.

7.3) Linearity check on dial II

Each step of dial II may be checked against the total of dial III using the same technique as described above. However, the summation of small errors can be excessive in 100 cumulative measurements and it is preferable to derive the linearity of the 100 step dials in 10 groups of 10 coils.

7.3.1) Connect the external potentiometer to the T2 and GA^+ terminals with the galvanometer in series or with the galvanometer connected to the galvanometer terminals of the external potentiometer. Simultaneously press the MEAS button and the T2/T3 OUT button so that both are locked down. Set dial II to position 90 (0.010 000 0 volt) and the external potentiometer to 0.01 volt.

7.3.2) Using the L, M and H^+ galvanometer keys adjust the current in either Pot. 1 or the external potentiometer or both, to obtain a balance between the two, as indicated by zero deflection on the galvanometer. Having obtained this balance release the galvanometer H^+ key, turn dial II to 100 (CK) and simultaneously press the MEAS and T2/T3 IN buttons. This operation, as will be seen from the circuit diagram, replaces the last 10 coils of dial II with the 0.5 ohm check resistor. These are nominally equal and the deflection of the galvanometer when the H^+ key is pressed, indicates the difference between them. Record this deflection.

7.3.3) Simultaneously press the MEAS button and the T2/T3 OUT button. Turn dial II to show 0.080 000 0 volt and adjust the external potentiometer dials and current to give a balance when the H^+ galvanometer button is pressed. Having obtained this balance, release the galvanometer H^+ key, restore dial II to 0.090 000 0 and simultaneously press the MEAS and T2/T3 IN buttons.

This operation replaces the 80-90 group of coils at dial II with the 0.5 ohm check resistor, Press the H^+ galvanometer key. Record the resulting galvanometer deflection.

7.3.4) Having obtained the difference ΔG_X between each group of 10 coils of dial II and the check resistor, tabulate the figures as for dial I, obtain the average difference etc., and plot the linearity of dial II.

7.4) Correction for the difference between the total of dial II and the average step of dial I.

Column 2 of Appendix 1 shows that the difference between the average step of dial I and the total of dial II is 0.2μV.

When both dials I and II are in use the total error must be the sum of the error for the nth step of dial I as read from the linearity plot for that dial and the error of the mth step of dial II as read from the plot for that dial and the error due to the inequality of dial II and the average step of dial I. It will be evident that the latter of these three corrections affects the final result only in proportion to the fraction of the complete dial which is in use.

The error for the mth step of dial II alone is given by:

$$E_{m2} = D_{m2} + \frac{m}{100} \overline{\Delta G1}$$

The error for the nth step of dial I used with the mth step of dial II is

$$E = D_{n1} + D_{m2} + \frac{m}{100} \overline{\Delta G_1}$$

7.5) Linearity check on dial III

7.5.1) Connect the external potentiometer to the T3 and GA^- terminals with a galvanometer in series between the two instruments or with the galvanometer connected to the galvanometer terminals of the external potentiometer.

7.5.2) Press the MEAS button and the T2/T3 OUT button so that both buttons

lock down together.

7.5.3) Link together the terminals marked CK3. This increases the current in Pot. 2 from 40uA at 1 volt to approximately 20mA. If a 1 volt Zener source is being used each step of dial III will then produce increments of 5mV. If the Zener source is not capable of supplying 20mA a 2 volt lead-acid battery may be used. This will give a current of 40mA and steps of 10mV on dial III. The increased voltage per step improves sensitivity and reduces the effects of varying thermal emfs in the external potentiometer which may be significant at the normal operating voltage level of dial III.

7.5.4) Check the linearity of dial III in the same way as described for dial II, comparing each group of 10 coils with the check resistor. In the case of dial III it is convenient to begin with the group CK to 90 and work down the dial 90-80, 80-70, etc.

7.5.5) Significance of linearity errors It will be apparent that an error of 1 ppm in a coil of dial I (1ppm of 0.1 volt) represents an error of 0.1uV (1 step of dial IV) and that an error as large as 0.01% in a coil of dial II (0.01% of 1mV) represents an error of the same magnitude, ie., 0.1uV. Also an error of 1% in a coil of dial III (1% of 10uV) introduces a voltage error of 0.1uV and in dial IV, in order to produce an error of 0.1uV a coil would require to be out of adjustment by 100%. For this reason checking facilities are not provided for dial IV. A sufficiently accurate check can be obtained by observing the magnitude galvanometer increments as dial IV is advanced step by step.

7.6) Standard Cell Dial

To check the standard cell dials against the measuring dials:-

7.6.1) Standardize Pot. 2 against Pot. 1 by the procedure described in Para. 6.3.5. Disconnect the standard cell galvanometer and short circuit

the SC GA terminals with a piece of clean untinned copper wire. Connect the SC terminals and the EMF terminals to the two sections of a two pole selector switch and connect the other side of this switch to an external potentiometer capable of supplying a stable 1 volt to 1.025 volt. Short circuit the TEST GA terminals.

7.6.2) Set the standard cell dial to 1.017500 and the STANDARDIZE switch to 1H and with the selector switch in the appropriate position connecting the SC terminals to the external potentiometer, adjust the current controls and/or measuring dials of the external potentiometer to obtain a balance against the 1.017500 setting of the standard cell dial.

7.6.3) Having obtained a stable balance as above operate the selector switch to connect the EMF terminals to the external pot in place of the SC terminals. Set the measuring dials to 1.017500 and with LM and H^+ sensitivity buttons re-adjust the setting of the measuring dials as necessary to obtain a balance. Revert to the SC balance against the external potentiometer to confirm that there has been no significant current drift during the comparison and repeat the check on the measuring dials.

7.6.4) Repeat as above for each switch position of the standard cell dial and record the errors between the standard cell dial and the measuring circuit.

7.7) Potentiometer Zero Error

Link the EMF terminals. Turn the four measuring dials to zero. Press the high sensitivity H^+ galvanometer key and adjust galvanometer sensitivity so that luV gives a deflection of 100mm. With all four dials at zero disconnect the battery and note the change in deflection. This change is due to the zero error of the potentiometer.

7.8) Other errors

In the measurement of low potentials systematic errors of the type described above may be negligible in the presence of errors due to poor technique or adverse environmental conditions. For example, themal emfs may be generated by very small temperature difference between pairs of junctions of dissimilar metals and may even occur at copper to copper junctions as for example at terminals which are not protected from air currents.

Leads which are used in the potential circuit should be solid wires rather than stranded and should be bare copper in preference to tinned copper. Insulation should be of good quality and the leads should be closely twisted to avoid magnetic pick-up. If measurements are being made on high resistance circuits it may be additionally necessary to shield the leads to prevent electrostatic pick-up. Electrostatic interference from static charges on the operator's clothing can be eliminated by grounding the GND terminal which is connected to the aluminum box lining. It is also helpful when trouble from electrostatic charges is experienced to connect the GND terminal to a metal plate on which the operator can stand. This brings the operator and the potentiometer shields to the same potential.

Leakage currents through the battery to ground and to the measured circuit which may have ground connections may be avoided by maintaining a high insulation resistance from the battery to ground.

8. ACCESSORIES

8.1) Galvanometer

The measuring galvanometer should have a sensitiv ity such that the smallest voltage increment of the potentiometer measuring dials can be easily detected when the resistance of the potentiometer and the circuits to be measured are

connected in series. It is also a matter of considerable convenience to have a control on the detector sensitivity. The Type 9460 Photocell Galvanometer Amplifier meets these requirements. The secondary galvanometer Type 9461A used with the amplifier has a 120-0-120 mm scale.

8.2) Volt ratio boxes and current measuring shunts to extend the voltage measuring range to 1500V and for current measurement up to 2250 amperes are available in the Guildline range.

8.3) External Selector Switch (Low Thermal Selector Switch Type 9145A).

The Type 9120 potentiometer has one pair of EMF terminals and it is intended that when it is required to make measurements on more than one external circuit a Type 9145A Selector Switch should be used. The 9145A Selector Switch gives facilities for the connection of four external circuits, each of which can be separately connected to the EMF terminals of the potentiometer by means of press buttons. The construction of the switch is similar to the construction of the galvanometer sensitivity keys with double pole precious metal contacts. Close thermal bonding is used and generation of thermal emfs in the switch is less than 0.01 microvolt.

APPENDIX 1

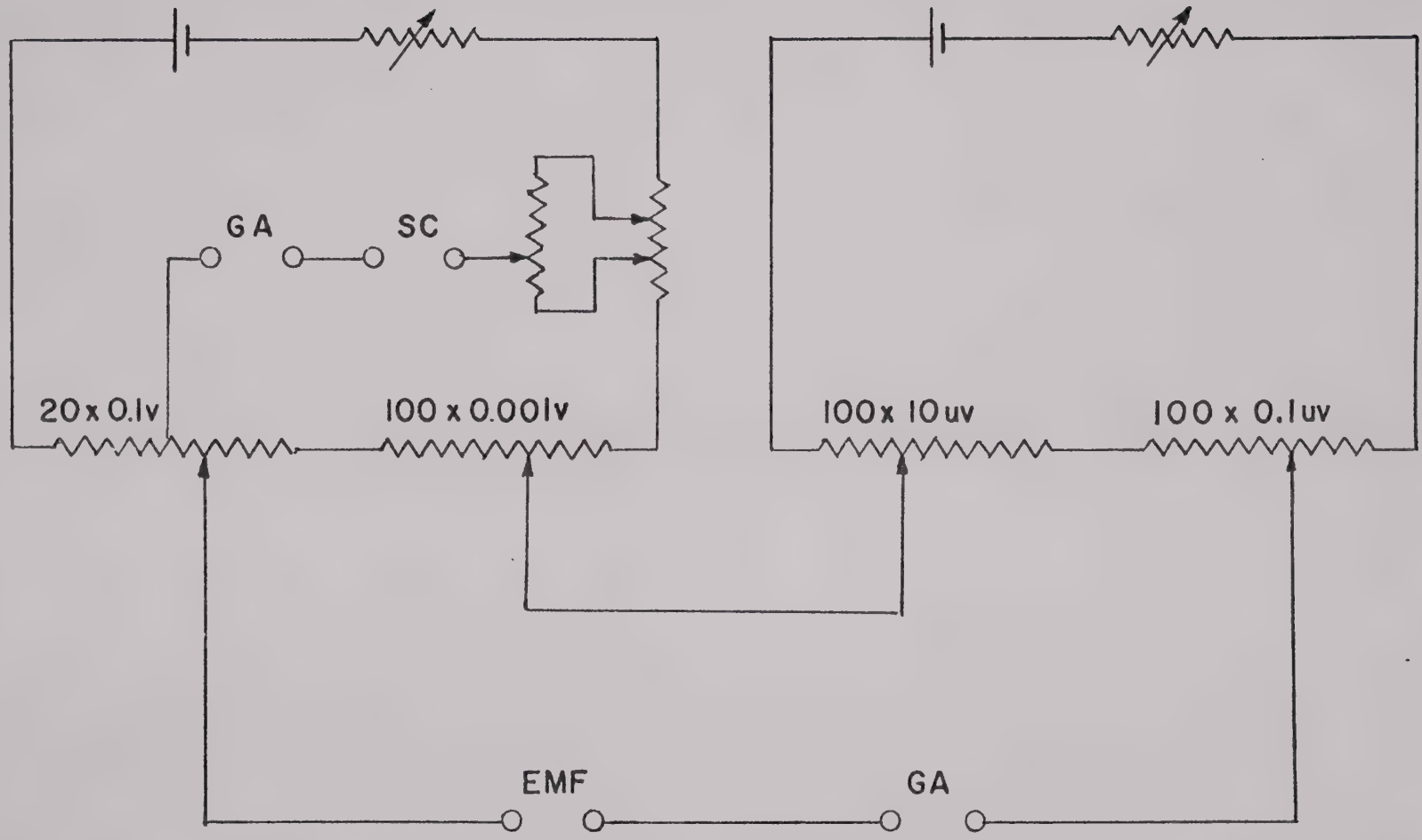
Example of linearity computation for first 10 coils of dial I

Coil No. (x)	Galvanometer deflection in mm due to difference between coil and reference (dial II total) (ΔGx)	Difference between each individual difference and the average difference ($\Delta Gx - \overline{\Delta G}$)	Deviation from linearity (Algebraic sum) in mm deflection (D_n)	Deviation in uV ($\frac{mm}{100}$)
1	+20	+40	+40	+0.40
2	+30	+50	+90	+0.90
3	-50	-30	+60	+0.60
4	-70	-50	+10	+0.10
5	-90	-70	-60	-0.60
6	-35	-15	-75	-0.75
7	+25	+45	-30	-0.30
8	-60	-40	-70	-0.70
9	-10	+10	-60	-0.60
10	+40	+60	0	0

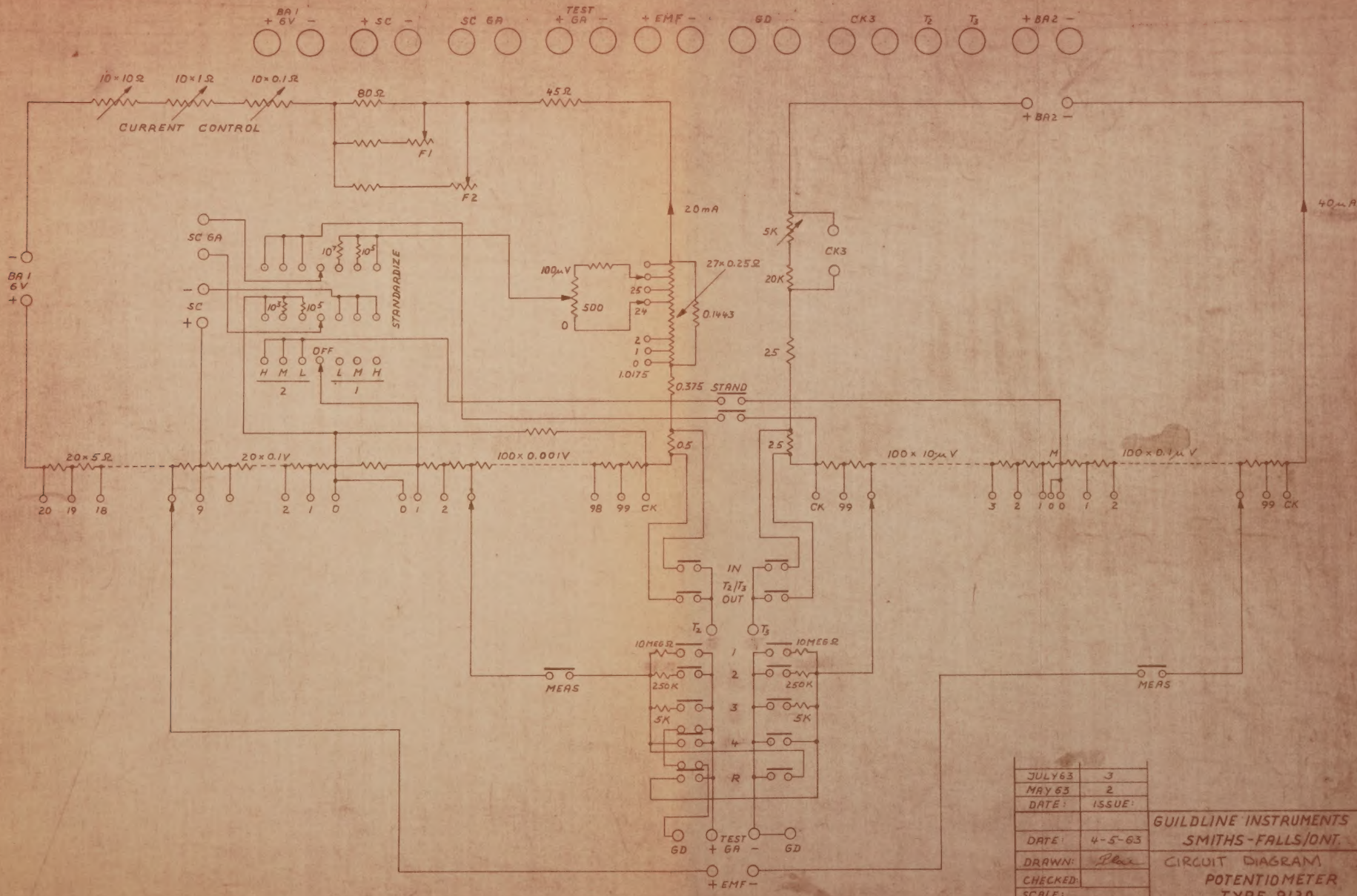
Total -200

Average difference $\overline{\Delta G}$ = -20

Galvanometer sensitivity = 100mm/uV



TYPE 9120 POTENTIOMETER



JULY 63	3
MAY 63	2
DATE:	ISSUE:
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DRAWN:	Plan
CHECKED:	
SCALE:	/

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CIRCUIT DIAGRAM
POTENTIOMETER
TYPE 9120
12159.01.04